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Mechanical Properties of Die-Cast Nonflammable Mg Alloy

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***Abstract*—**Tensile specimens of nonflammable AZ91D Mg alloy were fabricated in this study via cold chamber die-casting process. Dimensions of tensile specimens were 25mm in length, 4mm in width, and 0.8 or 3.0mm in thickness. Microstructure observation was conducted before and after tensile tests at room temperature. In the die casting process, various injection distances from 150 to 260mm were employed to obtain optimum process conditions. Distribution of $Al_{12}Mg_{17}$ phase was the key factor to determine the mechanical properties of die-cast Mg alloy. Specimens with 3mm of thickness showed superior mechanical properties to those with 0.8mm of thickness. Closed networking of $Al_{12}Mg_{17}$ phase along grain boundary was found to be detrimental to mechanical properties of die-cast Mg alloy.

***Keywords*—**Non-flammable magnesium alloy, AZ91D, die-casting, microstructure, mechanical properties.

I. Introduction

MOST magnesium alloys show very good machinability and processability, and even the most die cast parts can be easily produced. Cast, molded, and forged parts made of magnesium alloys are also inert gas weldable and machinable. Another aspect is the good damping behavior, which makes the use of these alloys even more attractive for increasing the life cycle of machines and equipment or for the reduction of sonic emission. Pure magnesium shows even higher damping properties than cast iron [1], [2] although these properties are highly dependent on the prior heat treatment.

Along with the excellent properties, there are some advantages to the application of these alloys. As already mentioned, the cold working abilities are very poor and the corrosion resistance of magnesium is very low. Besides, magnesium is very reactive. When cast, magnesium has a high mold shrinkage of approximately 4% when solidifying and of about 5% during cooling [3]. This high degree of shrinkage leads to microporosity, low toughness, and high notch sensitivity that cannot be ignored. This behavior as well as the high thermal expansion coefficient (10% above the corresponding value for aluminum) is often put forward as an argument against the use of magnesium alloys.

The use of magnesium die-cast parts in light construction and automotive applications has undergone a marked increase; the number of engineers knowing about the materials properties and the application possibilities as well as the advantages of magnesium parts in general is rising. Innovative and seminal solutions are the result of a close cooperation between raw material suppliers, founders, system suppliers, and the industry.

The castability of magnesium using die-casting process is well known to be excellent [4]. Its flow properties are much better than those of the non-ferrous metals aluminum and zinc. The good flow properties allow the casting of thin-walled parts and costs are reduced due to the fact that less material is needed. Structural parts for automotive applications can be easily cast, resulting in a tremendous weight reduction. Mechanical properties of die-cast magnesium alloys are, however, rarely investigated so far. In the present study, plate type tensile specimens of non-flammable magnesium alloy AZ91D were successfully fabricated by cold chamber die-casting process and the microstructure and mechanical properties were systematically investigated.

II. Experimental Procedures

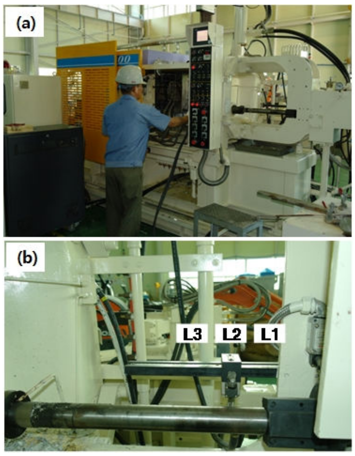

Fig. 1 Appearance of the die-casting machined used in this study (a) and its injection control part (b)

The material used in this study was AZ91D Mg alloy ingots containing some calcium and yttrium for non-flammability [5]. A cold chamber die-casting machine of 200 ton grade was used in this study to fabricate plate type tensile specimens. Gage length and width of specimen were 25 and 6mm. The

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thicknesses of specimens were 0.8mm and 3mm. The appearance of die-casting machine is given in Fig. 1 together with that of injection control area. Fig. 2 shows schematic illustration of mold and cavity for die-casting.

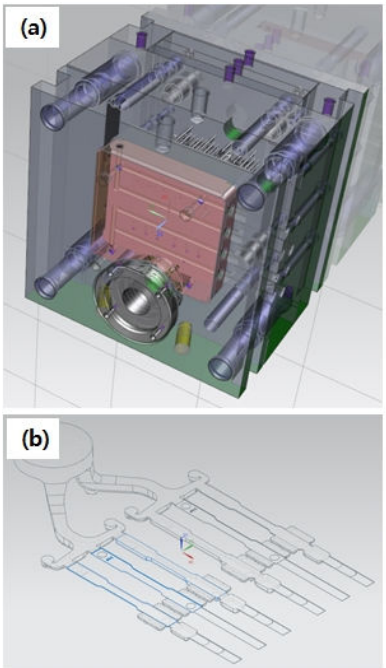

Fig. 2 Schematic illustration of die-casting mold (a) and cavity design for tensile specimens (b)

In the die-casting process, ingots were melted and then impressed into the mold with various speeds. In the present study, by varying injection distance depicted in Fig. 1(b) as L1, L2, and L3, injection speed was controlled. The injection distance taken in this study was from 120 to 280 mm.

Tensile tests were conducted on the specimens obtained by die-casting process at room temperature under the strain rate of $5\times10^{-4}/s^{-1}$. Microstructure of the specimens was also observed by optical microscopy before and after the tensile tests. Fracture surfaces were observed by a scanning electron microscopy.

III. Results and Discussion

Fig. 3 shows an example of die-cast tensile specimen of non-flammable AZ91D magnesium alloy fabricated in this study. In every charge of die-casting, two samples of 3mm thickness and two of 0.8mm thickness were produced. As shown in Fig. 3 (b), fabricated tensile specimen is very sound and has no defect on surface.

Fig. 4 shows typical flow curves obtained from tensile tests on specimens with thicknesses of 0.8 and 3mm at room temperature. Strength of specimen with 3mm thickness is somewhat higher than that of specimen with 0.8mm thickness. In fact, strength of die-cast tensile specimens showed very wide span exhibited in Fig. 5 for specimens with thickness of 0.8mm, in which tensile and yield strength were plotted as a function injection distances. It is very interesting to note that the widest span of strength is obtained at the injection distance of 240mm while the span of strength at the injection distance of 210mm is narrowest. The tensile strength of die-cast specimen with thickness of 0.8mm is very low, not exceeding 200 MPa, which is much lower than the strength of ordinary AZ91D magnesium alloy (about 230 MPa) [6]. In the case of die-cast specimens with thickness of 3mm as given in Fig. 6, on the other hand, fluctuation in strength at a given injection distance appears to dramatically decrease and tensile strength reaches to 240 MPa at the injection distance of 200mm. Interestingly, yield strength of specimens with thickness of 3mm shows very narrow window near 160 MPa. From the Fig. 6 (a), the optimum die-casting condition for the non-flammable AZ91D magnesium alloy used in this study can be deduced as the injection distance of 200mm.

Fig. 3 Appearance of the die-cast tensile specimen in as-cast state (a) and post treated specimen (b) fabricated in this study

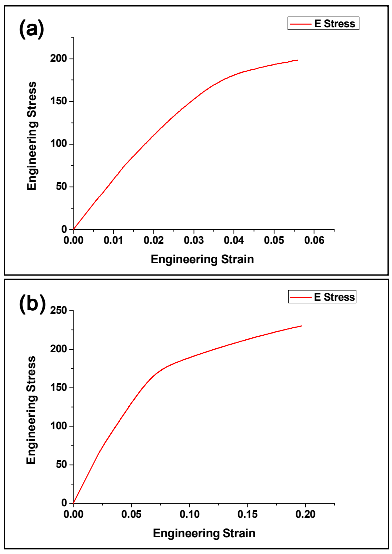

Fig. 4 Typical flow curves obtained from tensile tests conducted on specimen with 0.8 mm thickness (a) and specimen with 3 mm thickness (b)

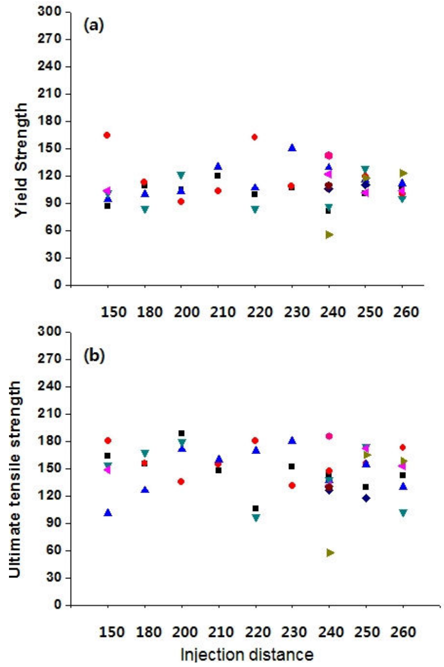

Fig. 5 Yield strength (a) and tensile strength (b) of die-cast specimens with thickness of 0.8 mm obtained at various injection distances

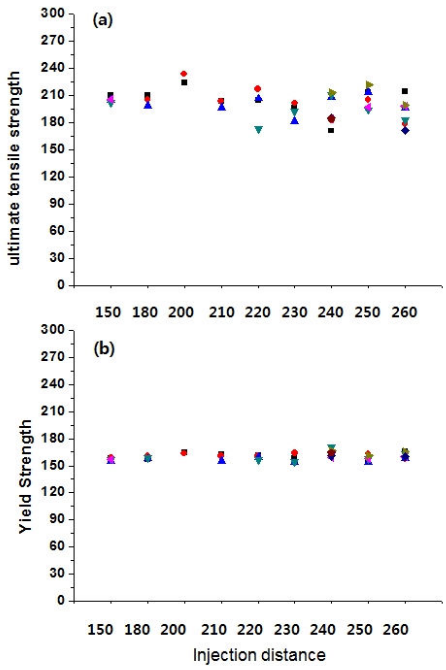

Fig. 6 Tensile strength (a) and yield strength (b) of die-cast specimens with thickness of 3mm obtained at various injection distances

Fig. 7 shows fracture surface of low strength specimen of 0.8 mm thickness die-cast at the injection distance of 260mm, in which we can observe the typical intragranular fracture as indicated by a circle [7]. Any other casting defects cannot be observed. Microstructure observed near fracture surface as given in Fig. 8 shows interesting feature, closed networks of β phase ($Al_{12}Mg_{17}$), which explains the intragranular fractural feature of Fig. 7.

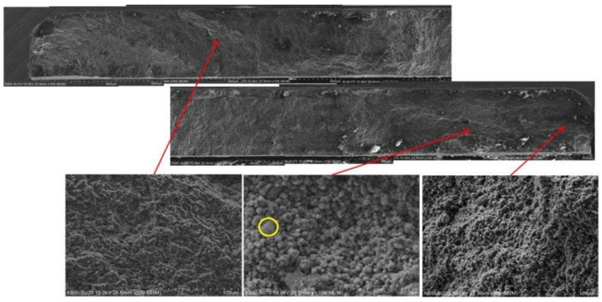

Fig. 7 Fracture surface observed in the specimen of 0.8mm thickness die-cast at the injection distance of 260mm, showing very low tensile strength

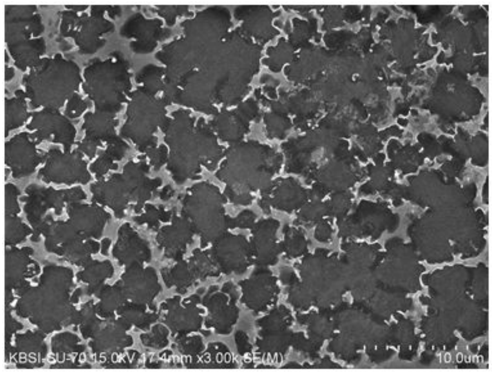

Fig. 8 Microstructure observed near fracture surface of the specimen of 0.8mm thickness die-cast at the injection distance of 260mm, showing very low tensile strength

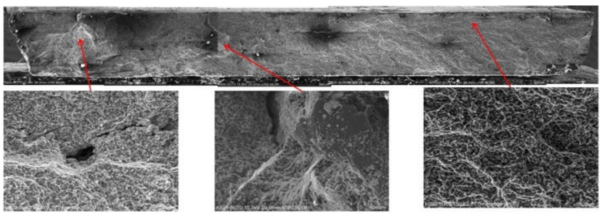

Fig. 9 Fracture surface observed in the specimen of 0.8mm thickness die-cast at the injection distance of 240mm, showing high tensile strength of 210 MPa

Fig. 9 shows fracture surface of high strength specimen of 3 mm thickness die-cast at the injection distance of 240mm, which is totally different from the feature of Fig. 7. The networking of β phase is the important factor detrimental to mechanical properties of die-cast magnesium alloy and the process conditions attributed to the networking should be removed in this regard. As shown in Fig. 10, die-cast specimen with high strength shows less closed network structure of β phase. The tendency is more clearly observed in the specimen of 3 mm thickness showing very high strength of 240 MPa as given in Fig. 11.

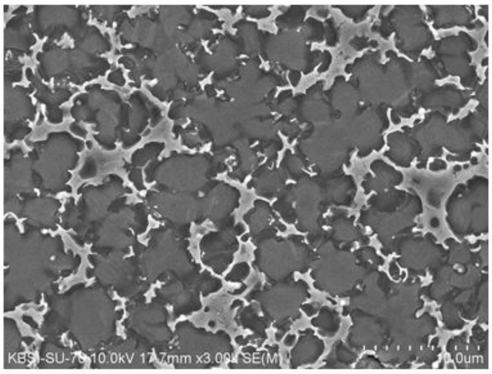

Fig. 10 Microstructure observed near fracture surface of the specimen of 0.8mm thickness die-cast at the injection distance of 240mm, showing high tensile strength of 210 MPa

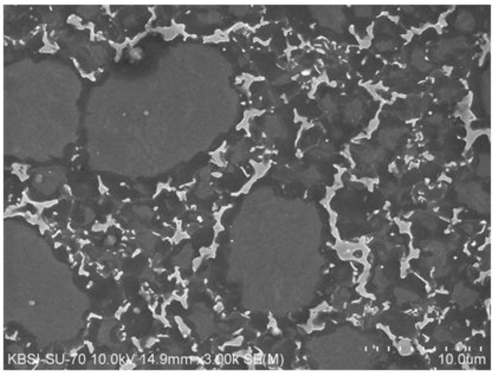

Fig. 11 Microstructure observed near fracture surface of the specimen of 3 mm thickness die-cast at the injection distance of 200mm, showing high tensile strength of 240 MPa

IV. CONCLUSIONS

In the present study, plate type tensile specimens of non-flammable magnesium alloy AZ91D were successfully fabricated by cold chamber die-casting process and the microstructure and mechanical properties were investigated. Fluctuation in strength of specimens with 0.8 mm thickness is much more severe than that of specimens with 3 mm thickness. Strength of the former is much lower than that of the latter. The closed networking of β phase was found to be the important factor detrimental to mechanical properties of die-cast magnesium alloy.

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